Impacts of boresight drifts on tech demo observations

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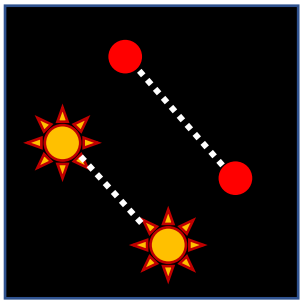
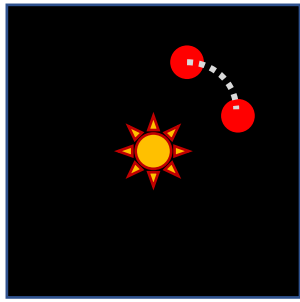
Types of drifts considered



- x/y drifts occur *only* when LOWFS tip/tilt loop is OPEN
  - Unocculted star observations (no light to LOWFS)
  - Faint star (V>5) observations
    - too little light to LOWFS to run at full speed.
    - LOWFS may be able to run at a reduced rate, but that is work to go.



- Rotation (clocking) drifts are not controlled
  - Can affect all CGI observations

- In this package, we only consider drifts that affect observations and/or calibration.
  - PACE and WFC have related requirements, but not included here

Summary: x/y and rotation drifts impact several observation types

L2-required observations

- Slit+prism calibration
  - xy drift especially.
- astrometric calibration
  - rotation drift especially, but also xy drift

Additional observing modes (PSP science cases)

- non-coronographic and faint star observations difficult or impossible
  - No protoplanetary disks (forming planets) around V<5 stars
  - Precludes observing any planetary companions to V>5 stars
  - May preclude many non-exoplanet science cases such as active galactic nuclei or evolved stars

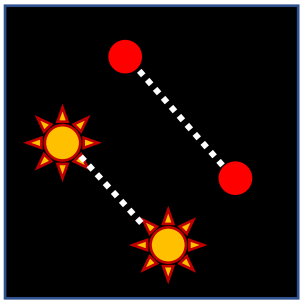
Summary: Desired drifts for CGI observations and calibrations

- *See backup slides for justification*

- **xy drifts ≤ 10mas per axis (1 sigma)**
  - Driven by slit spectroscopy requirement
  - Timescale >30min enables slit spectroscopy (longer is better).
  - Note: can tolerate 1 sigma jitter <~20mas (TBR) if it averages to zero over timescales of few minutes or less.

- **Max rotation change +/- 0.1 degree (1 sigma) around CGI image center**
  - Driven by astrometry requirement
  - Because there is no obvious way for CGI to track clocking, it must be consistent both on a single target and from target-to-target in order for astrometric calibration to be valid.
  - Must hold over timescales of days to weeks.

WFI-to-CGI boresight xy drift



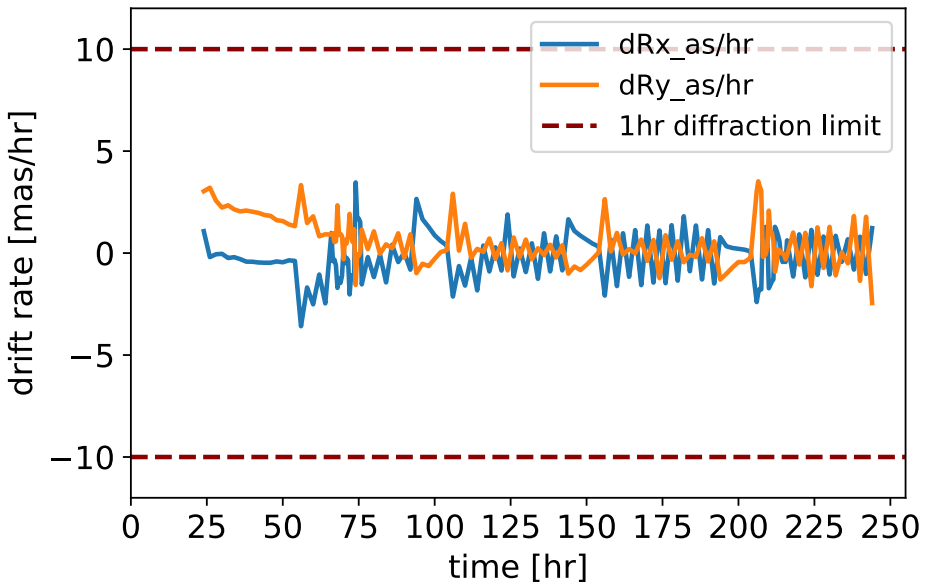
- Requirement: drift < 2” per hour
  - = 10mas every 20sec. Does not meet needs
- CBE on IC contribution: < 5mas/hr
  - including only IC effects (no CGI internal)
  - IC-only contribution is comfortably below needs

TODO

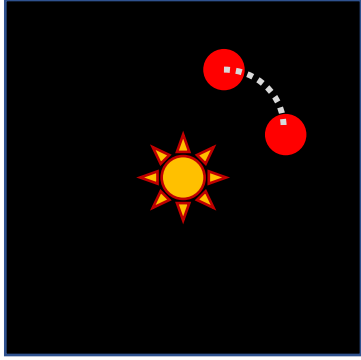
- evaluate boresight drift with upcoming OS8+cycle 2, which includes CGI internal model.

- Can we tighten the requirement?
  - Currently 99% margin vs OS7 sim
  - propose 1 sigma drift <20mas/hr
  - may use 1000sec if desirable to match timescale in WFI req’s

OS7. No CGI internal contribution



CGI boresight rotation



- **There appears to be no requirement** for on-orbit rotation drift rate (excluding ground-to-orbit shift)
- **There is currently no assessment** from STOP modeling.

- **TODO**
  - Assess CGI boresight rotation using upcoming OS8+cycle2
  - Propose requirement: maximum (1 sigma) boresight rotation drift of 0.1 degrees (over 1000hr??)
    - not including the initial ground-to-orbit shift

backup

Starshade does not have additional needs beyond those identified for coronagraph tech demo obs

From Thibault…

Acquisition

- o No LOWFS control assumed
- o CGI unobscured pointing acquisition procedure on DICAM needs to be possible (WSA-41).

Science:

- o Offloading to ACS is assumed (WSA-27), using measurements from LOWFS.
- o ACS tracking performance with respect to the offloaded tip-tilt assumed to be such that the total ACS residual is within 30 mas 3-sigma (WAS-25).
- o Allows meeting the 40 mas 3-sigma requirement for the average pointing error over a given frame (in 10-200 sec range) (WSA-24) and the 10 mas RMS Starshade pointing stability “need” (not an IRD requirement).

Calibration

- o Starshade calibration procedures not yet well-defined.
- o Expect similar calibration steps and therefore constraints for slit+prism spectroscopy with CGI and starshade.

Prism and IFS can meet BTR6 SNR requirements in allocated integration time

BTR6: (High-Contrast Imaging Spectroscopy) WFIRST shall be able to measure the spectrum of an astrophysical point source located between 0.27" and 0.53" from an adjacent star with a V_{AB} magnitude as dim as 5, with a flux ratio as faint as 5 10^{-8} over an 18% bandwidth at R=50 with an SNR=10 per spectral resolution element.

***Integration** time on target required to meet BTR6 requirements for a single spatial resolution element with **standard MUFs**, assuming an SPC Phase B coronagraph with 20190130 sensitivities. Table does not include slew or acquisition overheads or time on reference star.*

Delta mag at 730nm	IFS **integration** [hr]	Prism **integration** [hr] *
18.25 = requirement	18	10
19	65	34
20	430	450
21.5 = reflected light Jupiter analog	not observable	not observable

*** Note that prism has <u>extra</u> operational overhead compared to IFS due to slit alignment steps.**

For an OS6-like scenario the additional overhead is:

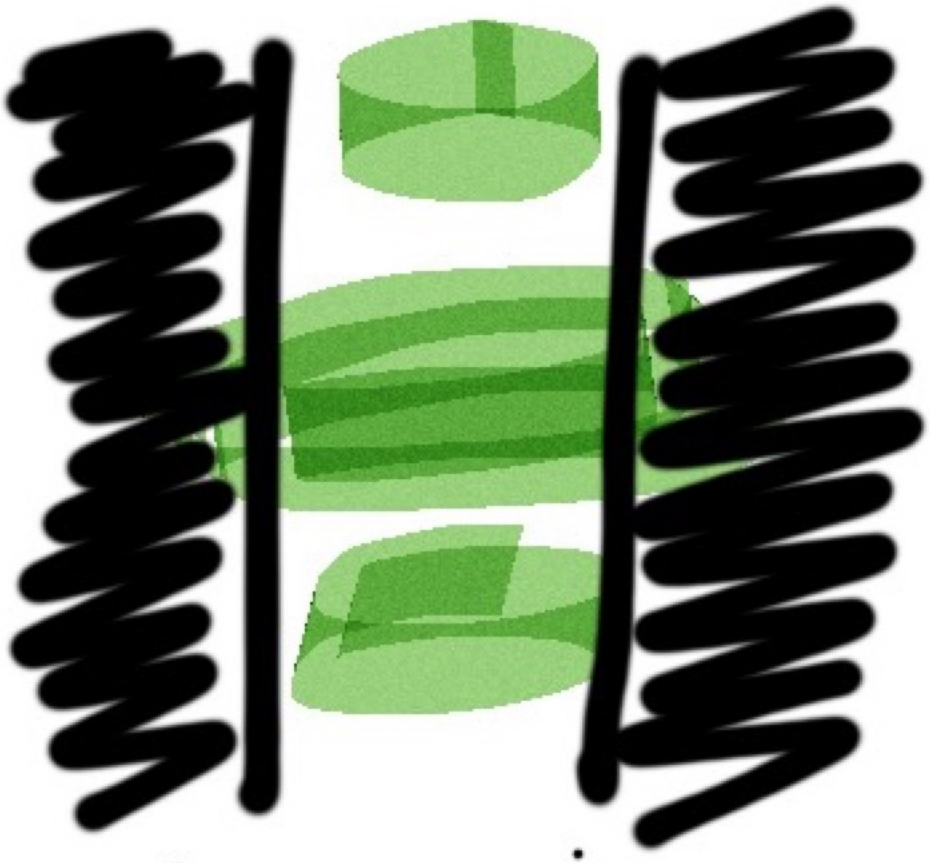
- Target star = t/2*0.5hr
- Reference star = t/4 * 0.5hr

Slit + prism descope summary

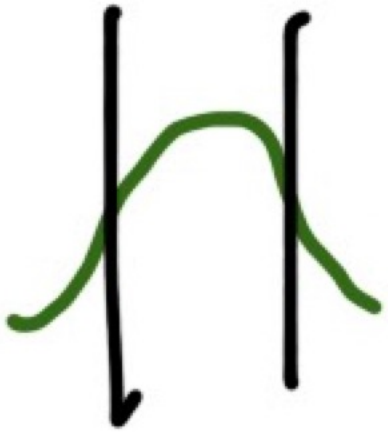
- likely to meet L1/L2 requirement assuming R≥50 at 730nn
  - BTR clarification needed because R is now wavelength-dependent.
  - R decreases with wavelength, and may fall below 50 at the red end of the band. This is acceptable from a science perspective.
- likely to match or exceed IFS sensitivity for equal amount of *clock* time
  - target observations + reference star observations + overheads
  - Slit alignment adds additional operational complexity.
- new WFC filters needed
- Obtaining non-coronagraphic spectra (ie: spectra of unocculted targets) is more challenging than in IFS mode, and requires further evaluation.
  - Impacts wavelength calibration and throughput/flux calibration as detailed in following slides

Slit + prism spectroscopy wavelength and throughput calibration

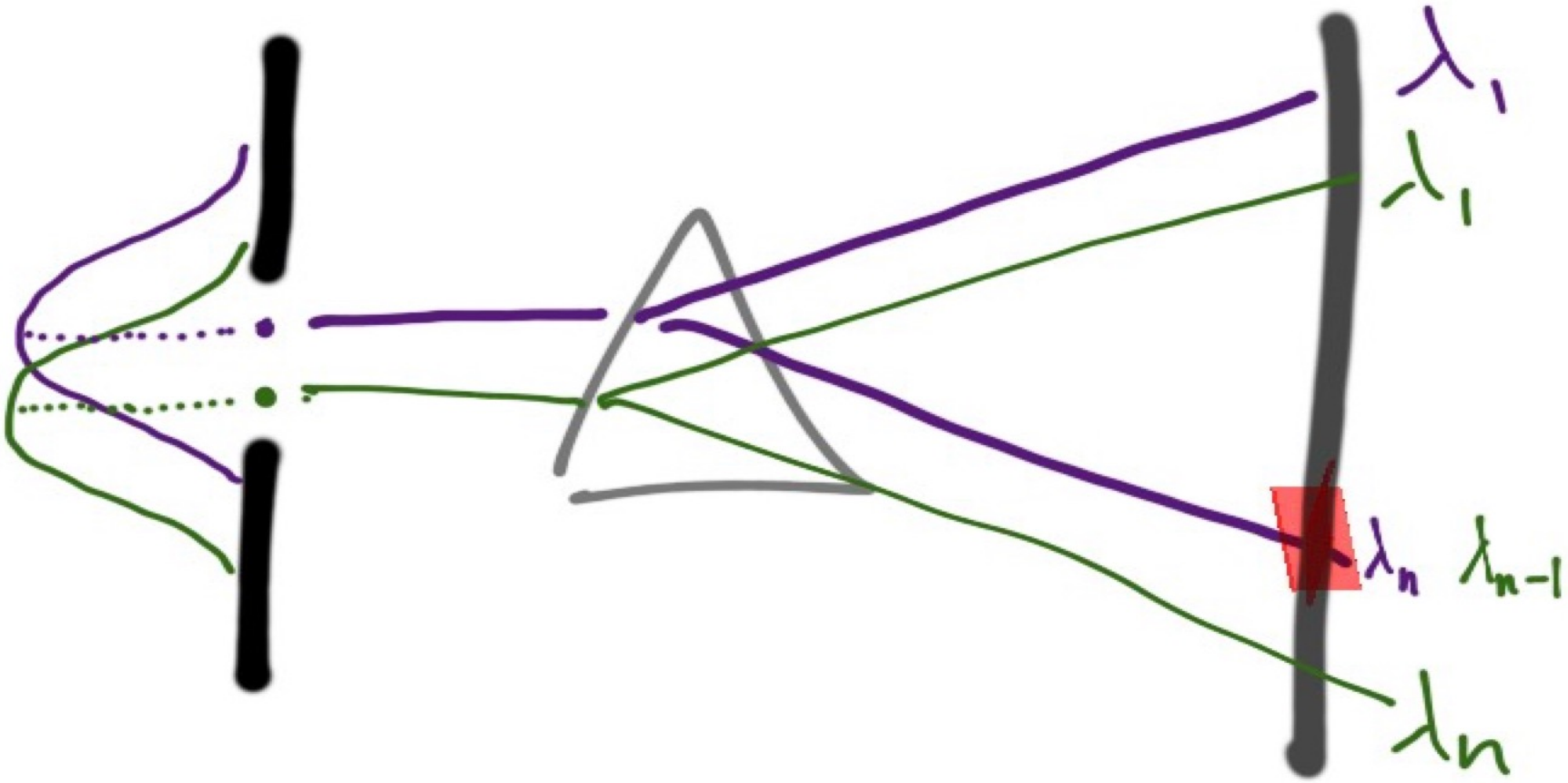
- best accomplished by observations of bright sources centered in the slit => No LOWFS
- Needed to calibrate the wavelength zero point (to 2nm)
  - To subtract speckles. Must know reference and target star spectra
- Must know wavelength dependent throughput to reconstruct planet spectrum.
- **IFS decoupled focal plane position from wavelength calibration and throughput. Slit+prism does not.**
- **Need to know target position in slit to 10mas = 0.5px**
  - **Jitter with zero mean is OK (up to a point), but xy drift is not.**
  - **Ideally, stable for 15min or more.**
  - For reference, HST/STIS tolerance for positioning within wide slits is ~10 mas = of 0.2 pixels
- **Does not drive rotation drift need** (can tolerate ~1 degree)



dispersion direction



FWHM
130mas

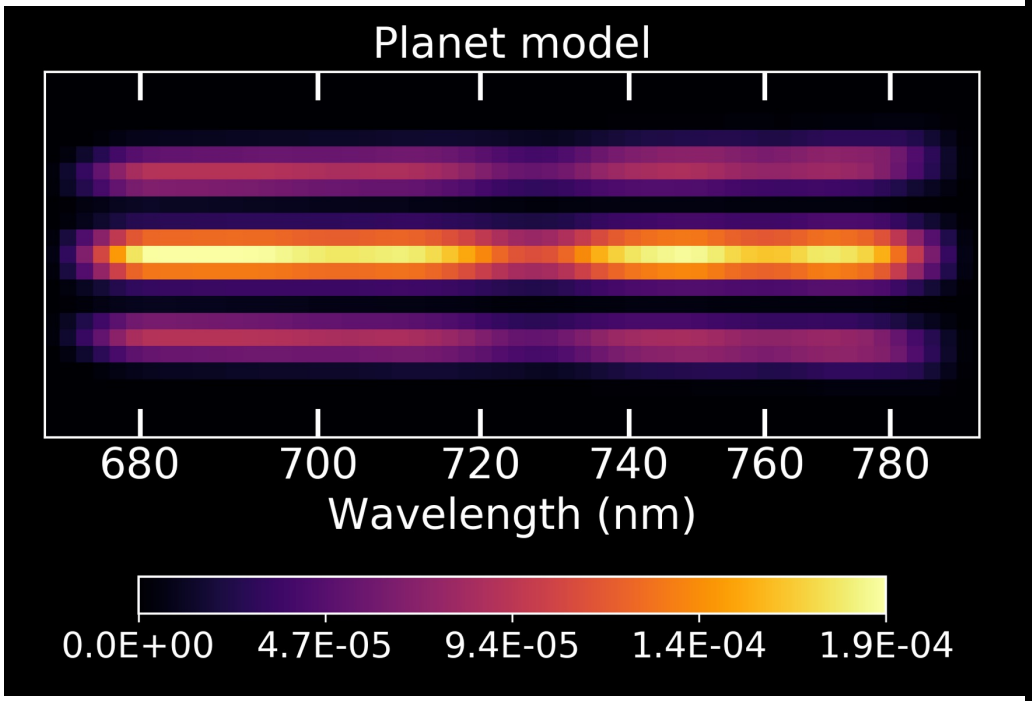


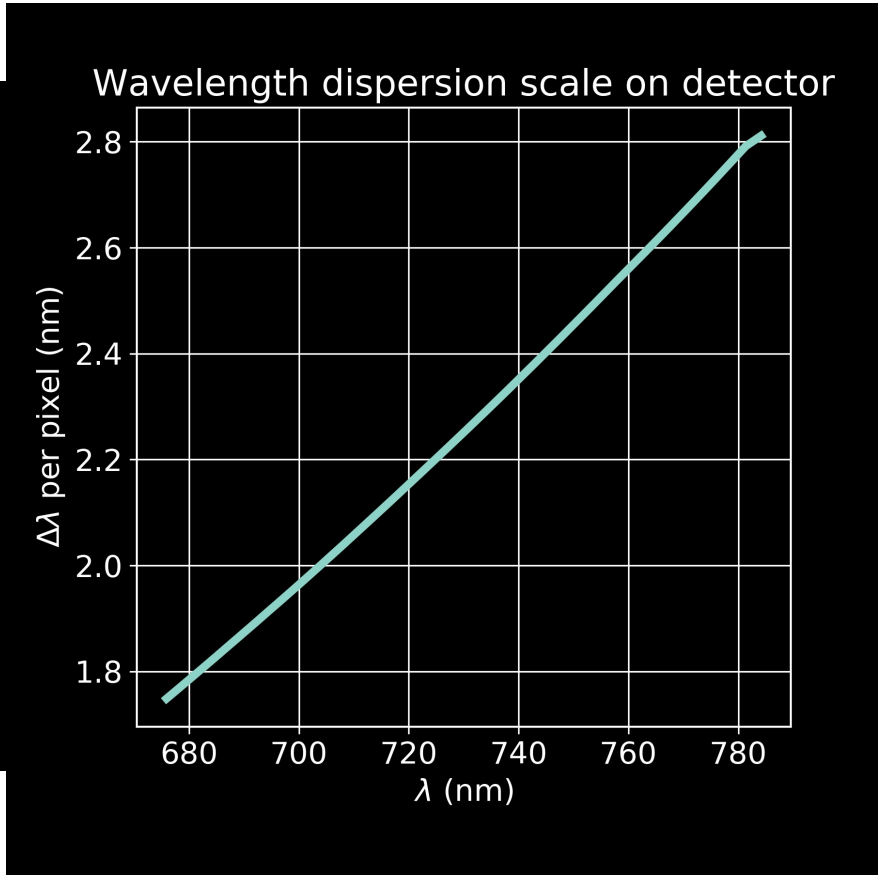
shift perpendicular to slit $\Rightarrow \lambda$ shift

$\Delta\lambda = \lambda_n - \lambda_{n-1} \leq 2\,nm$ (MRD 437)

Slit+prism wavelength calibration (2 nm accuracy; MRD-437)

- Calibration to 0.5px ensures 2nm accuracy
- 0.5px = 10mas

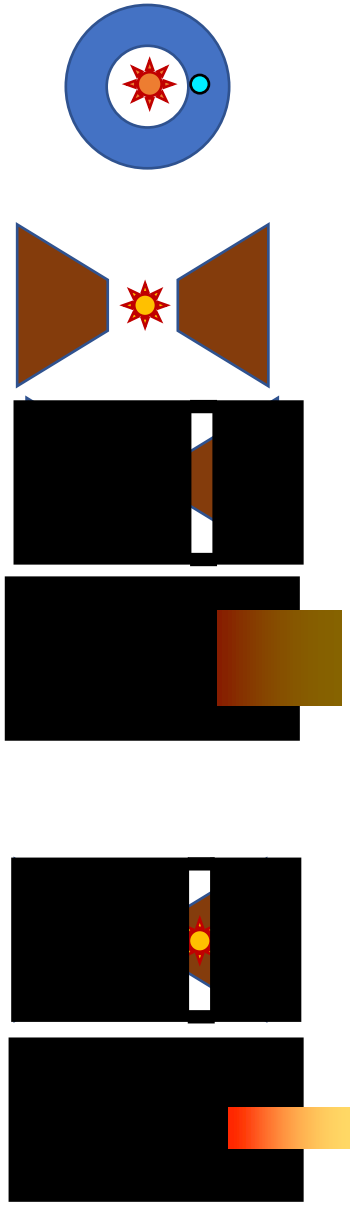




Prism concept of operations: part 1

Differences vs IFS operations are highlighted in purple text

- Pre-image planet in Band 1 imaging to determine location
  - Use to schedule spectroscopy, minimum 1 week wait
- Dig the dark hole in imaging mode on a bright *reference* star
  - WFC uses 3-3.5% sub-bands. Expected to meet 30hr WFC time requirement.
  - WFC needs full image information => no slit or prism in the path
- Align slit over area of interest on *reference* star
  - Match slit location on target star
- Long integration on *reference* star for RDI library
- Spectrum of un-occulted *reference* star
  - For wavelength/throughput calibration
  - No LOWFS => xy drift rate comes into play



Prism concept of operations: part 2

- Acquire *target* star & align with coronagraph
  - Remove slit and prism for alignment
- Re-Align slit over area of interest
- Long integration on target star
  - Keep WFC solution from reference star
- Spectrum of un-occulted *target* star
  - Same operational challenges as mentioned on previous slide

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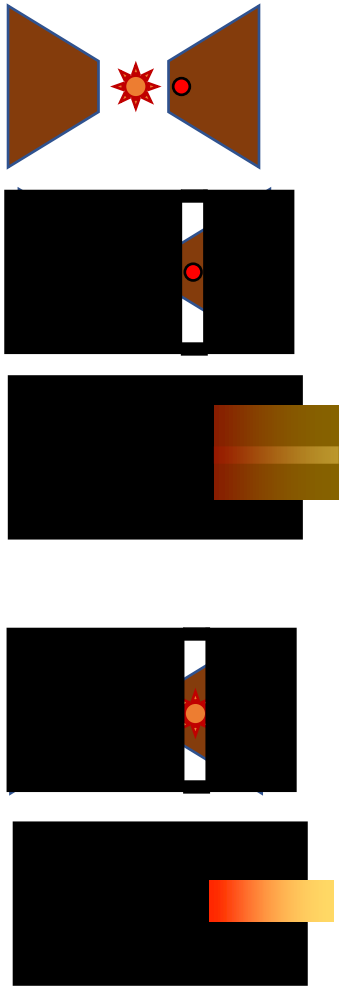
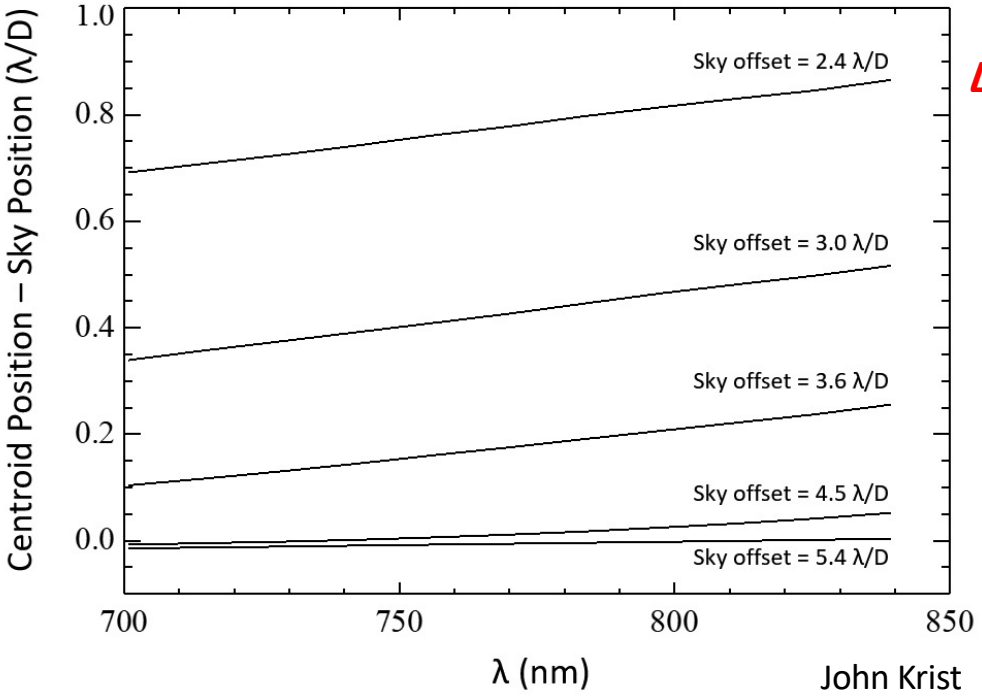
- *Return to reference star for dark hole touchup & reference images*
  - *Repeat slit acquisition procedure each time*

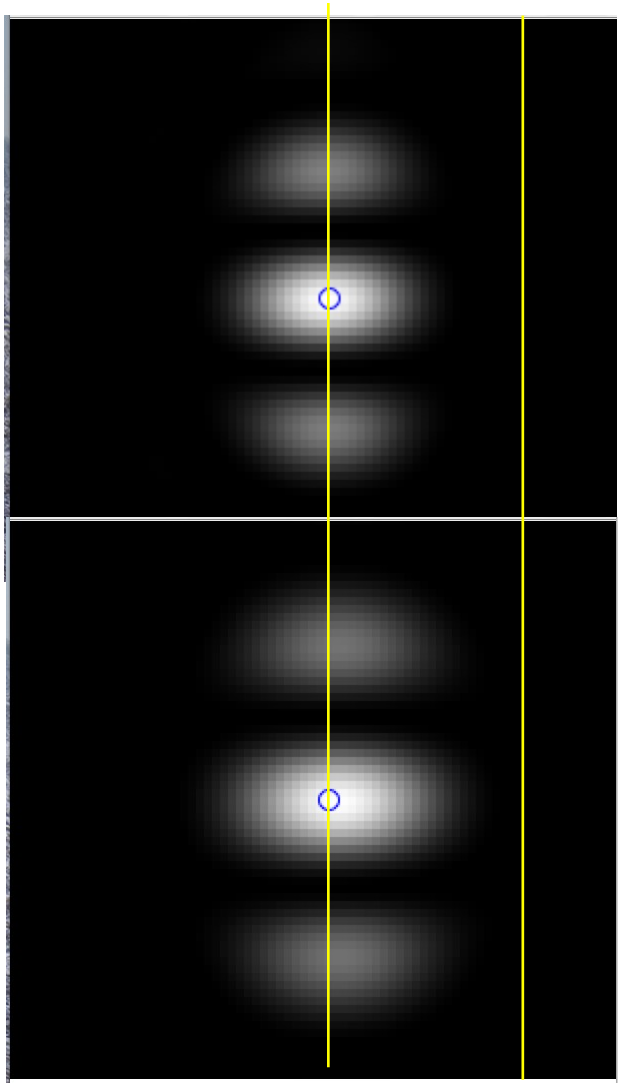


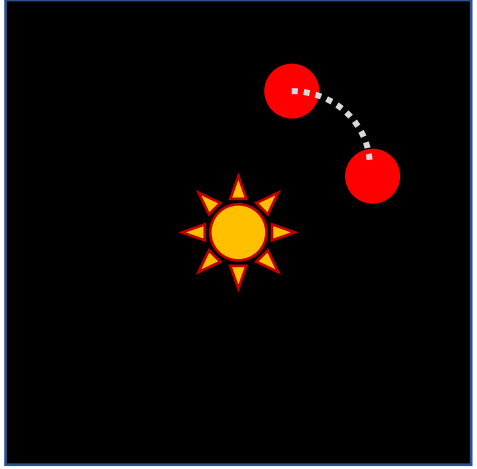
Modeling of PSF distortion near IWA and OWA required

At red end, more of PSF emerges from behind occult0r **=> appears shifted**



Δ ~ 0.2 λ/D
~ 10 mas
~ 2 nm



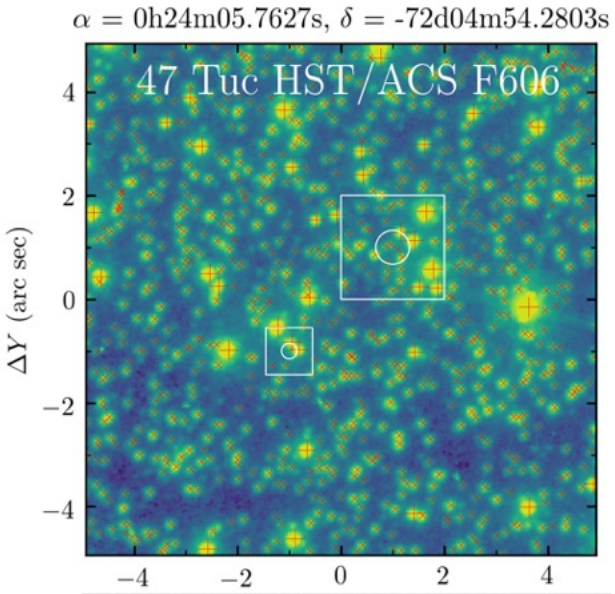


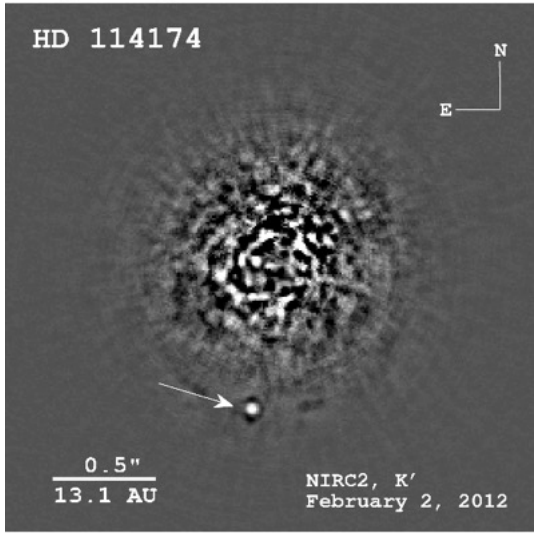
MRD-452 (5 mas astrometry) sets rotation drift limit

- For uncertainty in true north to contribute no more than half the error (2.5mas) in SPC wide FOV imaging mode (1.3” separation) **drift should not exceed 0.1 degrees (1σ)**
  - Initial ground-to-orbit shift does not matter, because we will calibrate in-orbit at the start of the tech demo phase.
  - maximum drift applies both during observation AND between calibrator and target => timescales of 1000hr or more
  - There does not appear to be a requirement for drift in orbit (only ground-to-orbit)

Most astrometric calibration fields do not have V<5 guide stars => xy drift

- Best: dense star clusters
  - many stars in the CGI FOV = many measurement vectors = good plate scale/orientation PLUS distortion
  - well calibrated with HST
  - No V<5 guide stars
- Alternate: Known self-luminous planets around V<5 stars
  - few measurement vectors
  - Few potential targets
- Can probably overcome xy drift in post-processing with “shift and add” so **does not drive xy drift need**





Additional science observations

- CGI requirements were written for coronagraphic observations of very faint planets next to very bright stars
- During PSP phase, scientists may want to observe other classes of targets that don't support LOWFS
  - Faint planets next to fainter (V = 6-15) stars
    - CGI could have unique capability to observe forming protoplanets, but there are no systems with V<5 stars
  - Regions around the central black holes of nearby galaxies (V ~ 15)
  - Material ejected by dying stars (V = 5-15)
- *Ideally*, CGI should support "diffraction limited" observing (<20mas xy drift) over >30min periods to allow spectroscopy and imaging of general purpose targets